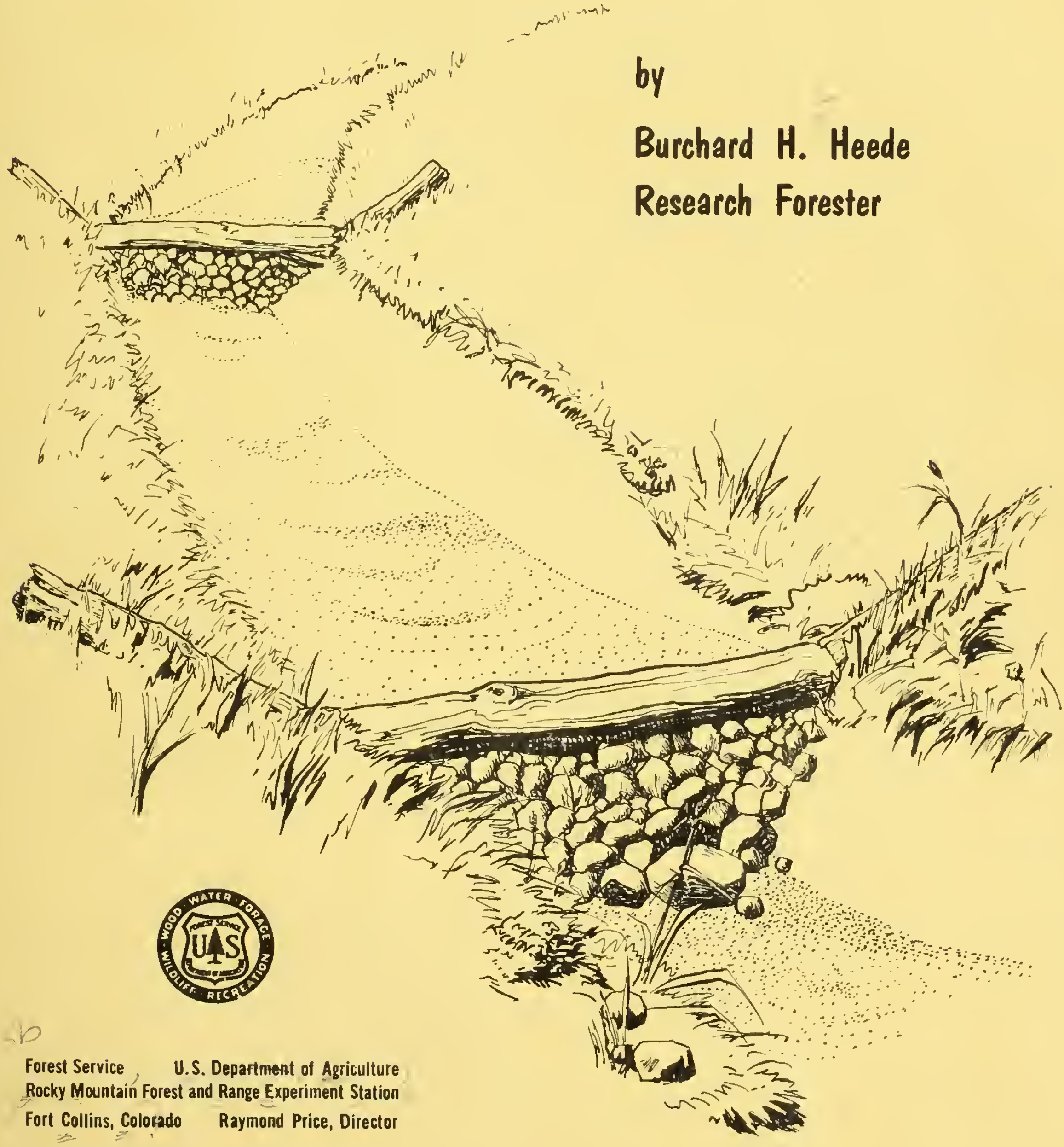
Station Paper No. 55

December 1960

A STUDY OF EARLY GULLY-CONTROL STRUCTURES in the Colorado Front Range



by

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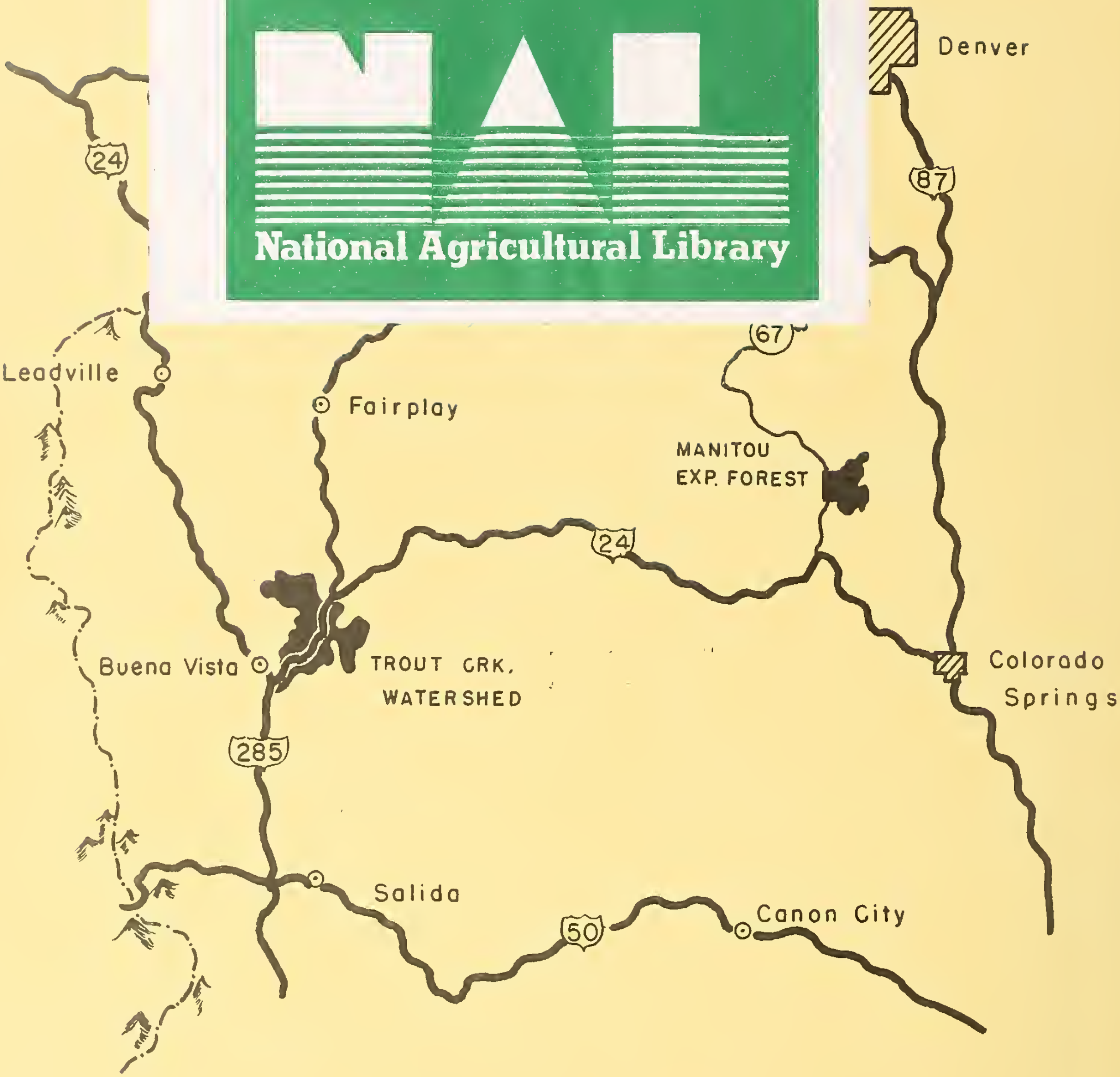

LOCATION OF STUDY AREAS

A STUDY OF EARLY GULLY-CONTROL STRUCTURES IN THE COLORADO FRONT RANGE

by

Burchard H. Heede, Research Forester[1]

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[1] Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained in cooperation with Colorado State University at Fort Collins.

A STUDY OF EARLY GULLY-CONTROL STRUCTURES IN THE COLORADO FRONT RANGE

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INTRODUCTION

The control of gullies is an important step in watershed rehabilitation. Gully control designed to fix valley bottoms at a certain base level stabilizes the valley floor through sediment accumulation in the gully channel. This reduces sediment deposition in river streambeds and enhances the quality of water supplies. Benefits of a gully-control program accrue to both on-site and downstream users alike.

PURPOSE

The purposes of the present study were:

1. To evaluate gully-control structures installed 20 to 25 years ago on the Pike and San Isabel National Forests.

2. To show the role of check dams in gully control.

METHOD

As a basis for estimating stormflow at a particular structural site, a design storm with a total of 2 inches of precipitation was used. Such a design storm was computed from the records at the Manitou Experimental Forest.

Average infiltration curves were established for the different vegetation-soil complexes (i.e., open timber-granitic, grass-granitic alluvium, etc.). Application of these curves to the rainfall pattern of the design storm yielded the rainfall excess (runoff) for each of the vegetation-soil complexes.

The peak flow from the storm was obtained by plotting the flow distribution of 10-minute periods in relation to their time difference on one chart.

To facilitate the survey of the watersheds and their drainage basins, a radial-line plotter was used on aerial photographs to determine:

1. Total acres of each drainage basin;

2. Acres in drainage segments;

3. Acres of vegetation-soil types within each drainage segment.

Peak flows at a given structure were determined by multiplying the acres in a segment above the structure by the peak flows per acre for the different vegetation-soil complexes within the segment.

Discharge rating curves were constructed for 1-foot-long broadcrested weirs of different heights and different breadths.

Photographs are the only record of the rehabilitation work in the 1930's. Therefore, the intended purpose of the structures was interpreted from the photographs taken at the time of construction. Early reports state that the overall purpose of the check dams was "to establish new base levels in rejuvenated channels" (Bailey and Croft, 1937).

Within limits the deposition of sediment behind a dam indicated a success and the lack of deposits a failure. Sometimes, it was found that a dam accomplished its objective but failed at a later date. In the case of deterioration of the construction material, the structure was considered a success if it apparently accomplished its purpose during the life of the construction material.

Tape, survey rod, and Abney hand level were used to determine original valley bottom slope, channel gradient before and after treatment, and channel and structural cross sections. The structures were numbered and the observations are summarized in table 1, page 42. A special field-data form for surveying and evaluating gully control structures was designed (see fig. 29, page 41.

THE STUDY

NURSERY GULLY SYSTEM, MANITOU EXPERIMENTAL FOREST

The Manitou Experimental Forest is situated in the Colorado Front Range 28 miles northwest of Colorado Springs in the upper headwaters of the South Platte drainage. The average annual precipitation is 15 inches. The critical factor for erosion is the cloudbursts of high intensity and short duration during the summer months.

The watershed of the Nursery gully system is within the ponderosa pine-bunchgrass zone and covers 360 acres. It is rather long and narrow, with the main axis running from east to west. The main stream course is 1.5 miles long. It starts in the forested headwaters at an elevation of about 8,000 feet; follows the main valley floor, covered by open timber stands and grasslands; and then discharges into the flood plain of Trout Creek at approximately 7,500 feet. The forest occupies 80 percent of the total drainage area. The soils are derived mainly from Pikes Peak granite. Slopes at the headwater area range between 20 and 30 percent, but the maximum slope of the valley floor is 10 percent. The ephemeral flow has cut gullies of varying width and depth in the drainageways. Measured maximum gully width was 46 feet and maximum depth was 6 feet.

Channel characteristics, treatment, and present-day conditions are shown in figures 1-10.

Figure 1.--The upper drainage of the Nursery gully follows an abandoned wagon road that is still visible where gullying has not taken place. Gully erosion is very active; headcuts mark the beginning of individual gullies. (Height of rod = 5.5 feet.)

Figure 2.--Downstream view. The discontinuous gully loses depth rapidly downstream. Five discontinuous gullies follow each other until a fan, caused by sediment depositions, designates the end of this gully system. Here, the fan merges with the original valley floor. Sixty-five feet below this point the original valley bottom is dissected again by a headcut and a new string of discontinuous gullies begins. The total length of this upper drainage segment is one-quarter of a mile. (Height of rod = 5.5 feet.)

Figure 3.--Upstream view of a continuous channel photographed in July 1936. This channel follows the string of discontinuous gullies and is 3,600 feet long. Headcuts of a small magnitude (0.5 to 0.75 foot deep) in the upper part of the continuous gully indicate that discontinuous channels joined into one continuous gully. This gully reaches a depth of 4 to 6 feet that is maintained downstream to a point close to the flood plain of Trout Creek. Here, the longitudinal channel profile becomes concave and channel depth decreases rapidly. In 1936-37 this continuous channel was treated by the Civilian Conservation Corps. Check dams and bank revetments were installed. Earth, logs, loose rock, and galvanized wire were used in the construction. Willow (Salix spp.) and New Mexican locust (Robinia neomexicana A. Gray) were planted in the channel and around the installations. Since the time of treatment, cattle grazing was reduced to a moderate intensity. Check dams were spaced in the gully by the rule that the height of the dam crest is in a horizontal line with the toe of the next upstream dam (head-to-toe rule). By this method stilling pond conditions were approached between dams and sediment accumulations were facilitated.

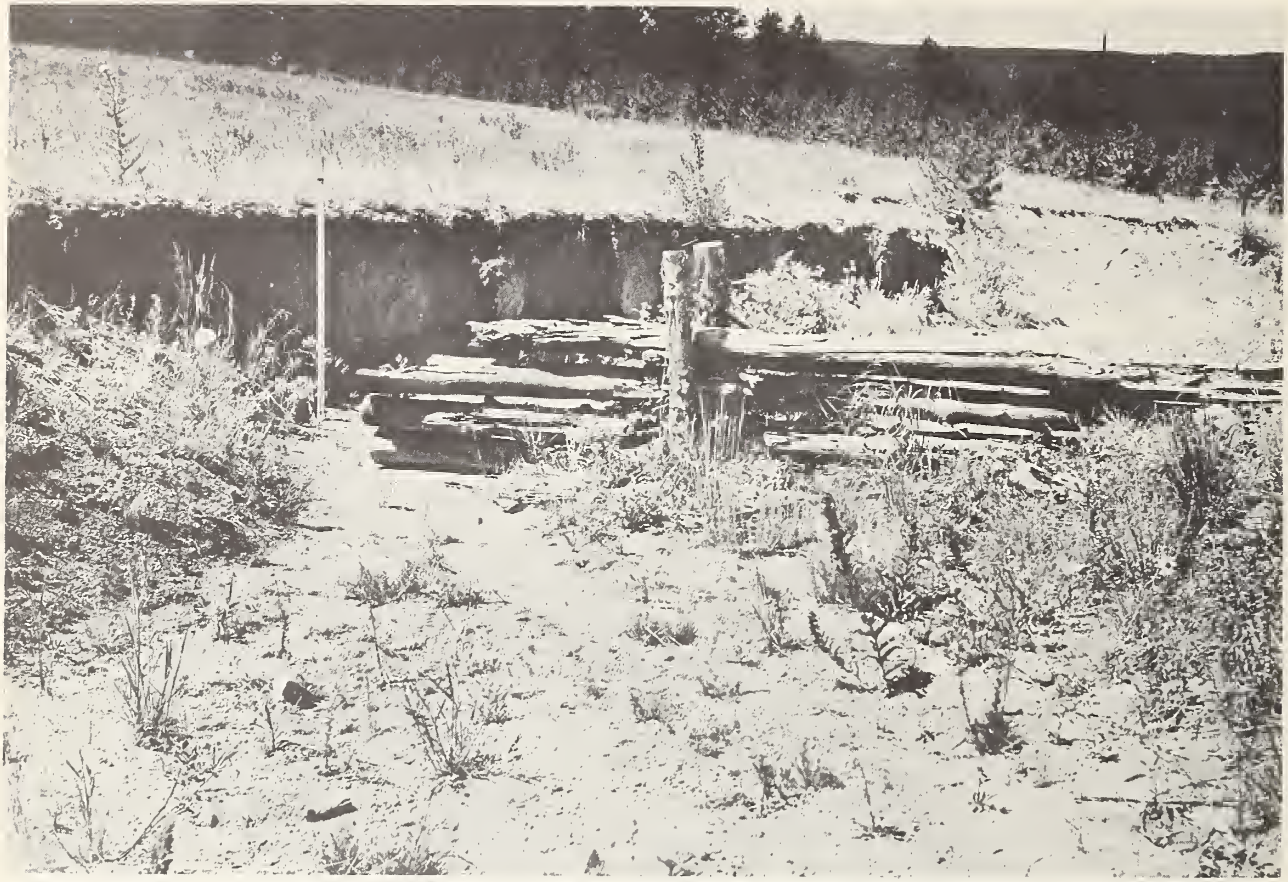

Figure 4.--Structure No. 1 is the first check dam installed in the upper reach of the continuous gully. The log dam was keyed 2 feet into the solid channel bank and reinforced by layers of loose rocks. The stream went around one end of the dam and widened the gully 5 feet as shown by the vertical bank. This widening probably took place soon after the structure was installed.

Figure 5.--At structural site No. 10 a headcut undermined the double log dam in the center. This headcut is now 12 feet upstream from the structure and is still active. The individual dams of the structure were connected by beams and the logs were tied with wire. Originally, the space between the dams was filled with earth and tree branches. Sediment accumulated to a height of 3.5 feet behind the dam. Planted willow and locust grow on the deposits.

Figure 6.--In the channel reach below structure No. 10 a new gully, caused by the headcut shown in figure 5, dissects the sediment deposits that were accumulated by a lower structure. The new gully meanders around the willow stands. With increasing channel depth the flow undercut the willows, tumbling them into the new gully. Erosion was accelerated by the soil loosened by the falling willows. (Height of rod = 5.5 feet.)

Figure 7.--(Upstream view.) Dam No. 11 accumulated considerable sediment until the headcut, presently located at structure No. 10, progressed through the dam and undermined it. The present channel is 2.5 feet lower than the original channel at time of treatment.

Figure 8.--Dams No. 12 and No. 13 are the last structures in the gully. Dam No. 13 was installed 180 feet above the gully mouth. The dimensions for this dam site were as follows:

Estimated channel cross section at time of construction = 11 × 19 × 5 feet;

Present channel cross section = 20.5 × 27.5 × 5.3 feet.

The estimated original structural dimensions were:

Height of dam = 4.2 feet;

Length of dam crest = 12.5 feet.

Both structures failed. The channel bottom at dam No. 12 was lowered by 1 foot since time of construction; the base level at dam No. 13 stayed at approximately the same elevation.

Figure 9.--Where the main gully and a tributary join, crib jetties were installed at a 45° angle to the direction of the main stream. The flow from the tributary forces the main stream against the bank opposite to the point of inflow. Here, the gully had widened before the jetties were built. No bank erosion occurred after treatment. The opposite bank shows signs of cutting that took place during the early years of treatment.

Figure 10.--Willow plantings in the erosion channel survived well, but only a few locust plantings survived. In some places very dense stands of willows developed from root cuttings. Flows of high velocity moved these cuttings downstream. Where the velocity decreased, the cuttings were deposited and grew into dense stands. Often the gully had widened where these dense stands occurred.

UPPER TROUT CREEK GULLY, SAN ISABEL NATIONAL FOREST

The Trout Creek watershed, a part of the Upper Arkansas Valley, is 5 miles east of the city of Buena Vista. U. S. Highway 24 traverses the drainage basin.

In 1957 rain gages were installed in the lower end of the watershed. Total precipitation for 1958 amounted to 7.31 inches and for 1959, 15.00 inches. Storms of high intensity and short duration are common. Long-term weather records are not available.

The upper Trout Creek gully starts as a series of shoestring gullies below Trout Creek Pass at an elevation of approximately 9,400 feet. In the main valley floor, the ephemeral stream runs in a continuous channel that enters the wide valley of Chubbs Park at about 8,900 feet. This drainage is about 1.5 miles long and covers 800 acres. Maximum gully width is 64 feet and maximum depth is 12 feet. Average channel depth ranges between 4 and 6 feet. At the lower end of the watershed, the longitudinal gully profile becomes concave and channel depth decreases.

Soils are derived from sedimentary material, mainly shale, siltstone, and sandstone. The vegetation type is ponderosa pine-bunchgrass. Forests occur on the headwater area and on the ridges surrounding the drainage basin. They occupy 70 percent of the area; the remaining portion is grassland.

Gully characteristics, gully-control measures, and the present-day conditions of channel and structures are described by figures 11-16.

SMALL TRIBUTARY GULLY, TROUT CREEK WATERSHED, SAN ISABEL NATIONAL FOREST

The Small Tributary gully is a side branch of a larger erosion channel that feeds its ephemeral flow into Trout Creek. The drainage area of Small Tributary covers 2 acres. The shallow residual soils are derived from decomposed granite rocks and are of low fertility. Vegetation is mostly bunchgrasses, with a few pinyon (*Pinus edulis* Engelm.). Gully characteristics and mechanical treatment are illustrated in figure 17.

REUTER GULLY, TROUT CREEK WATERSHED, SAN ISABEL NATIONAL FOREST

Reuter gully, a tributary to Mushroom Gulch that discharges its ephemeral flow into Trout Creek, has a length of 0.5 mile and a drainage area of 75 acres. The soils are developed from granite. In the lower end of the basin the soils are more severely eroded, and nearly all of the original surface layer is lost. The ridges surrounding the drainage are covered by open stands of ponderosa pine (*Pinus ponderosa* Laws.). Bunchgrasses occupy most of the grassland on the valley floor.

The gully starts in the headwaters as shoestring gullies that join into a continuous channel on the main valley floor. Approximately one-third (745 feet) of the total gully length was surveyed. Maximum gully depth was 5.5 feet and maximum width was 25.5 feet. The treatment of the gully and its present condition are illustrated and described by figures 18 and 19.

Figure 11.--In 1933-34, the U. S. Civilian Conservation Corps treated the gully by check dams and willow plantings. In the upper part of the watershed shown here the channel banks were graded to an angle of rest. Since 1937 no livestock have grazed the national-forest land that makes up about 90 percent of the watershed. The remaining 10 percent is State owned and lies at the drainage mouth. Here, grazing continues. Treatment started in the headwater area where small check dams made of logs or loose rocks were spaced 5 to 10 feet apart in the shoestring gullies. In the main gully, the spacing was determined by the head-to-toe rule, and many structures were installed. This is illustrated by the following data:

Length of channel segment = 825 feet;

Number of check dams = 28;

Average distance between structures = 29.4 feet.

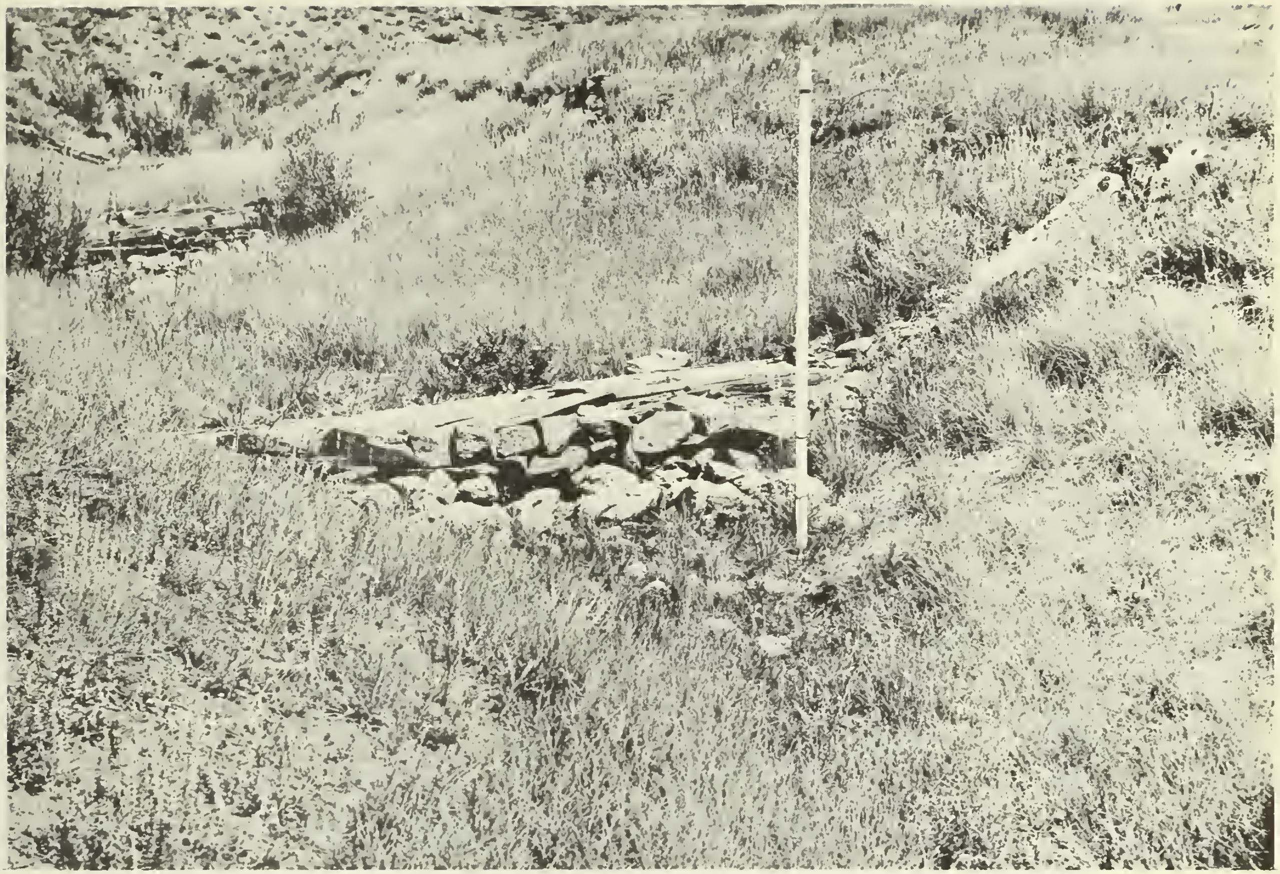

Figure 12.--View looking upstream at structure No. 5. This is a successful log dam reinforced by loose rocks. It is anchored 2 to 3 feet deep into the solid channel banks. Logs, installed into the slots of the dam keys, extended about 1 foot into the channel and the crest of the waterfall could not touch the banks. Below the dam an apron of loose rocks is imbedded in the gully floor. The gully banks were graded to the angle of repose. (Height of rod = 5.5 feet.)

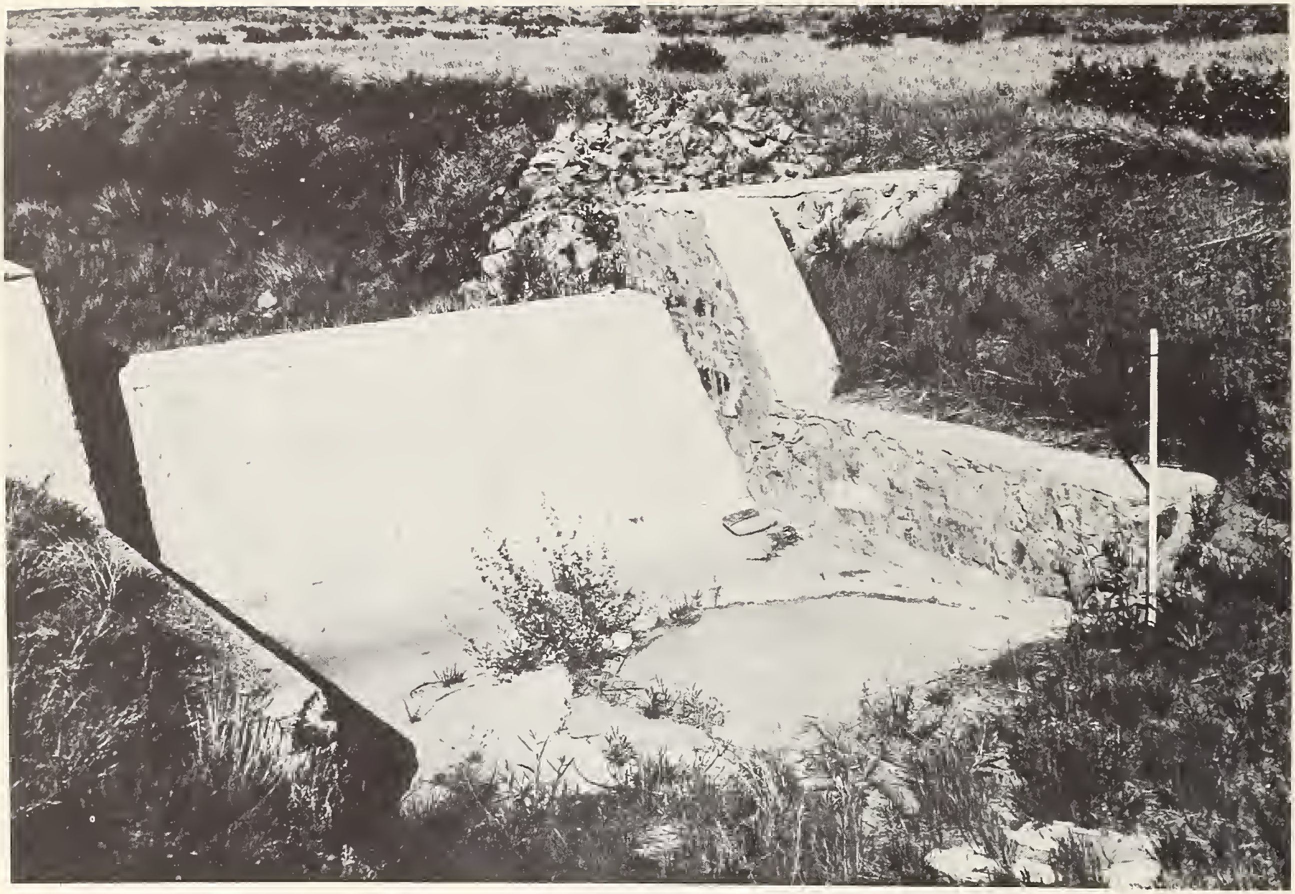

Figure 13. --Further downstream the gully bordered U. S. Highway 24 before the relocation of the highway in 1938. As this gully segment still eroded following treatment, the log and rock check dams were replaced by five masonry drop structures in 1937. Their heights range from 5 to 5.5 feet. All dams were successful. The upper three structures accumulated sediment to spillway crest, while at the two lower structures sediment depositions remained 2 to 3 feet below dam height. Since the concrete is deteriorating, the masonry structures need repair.

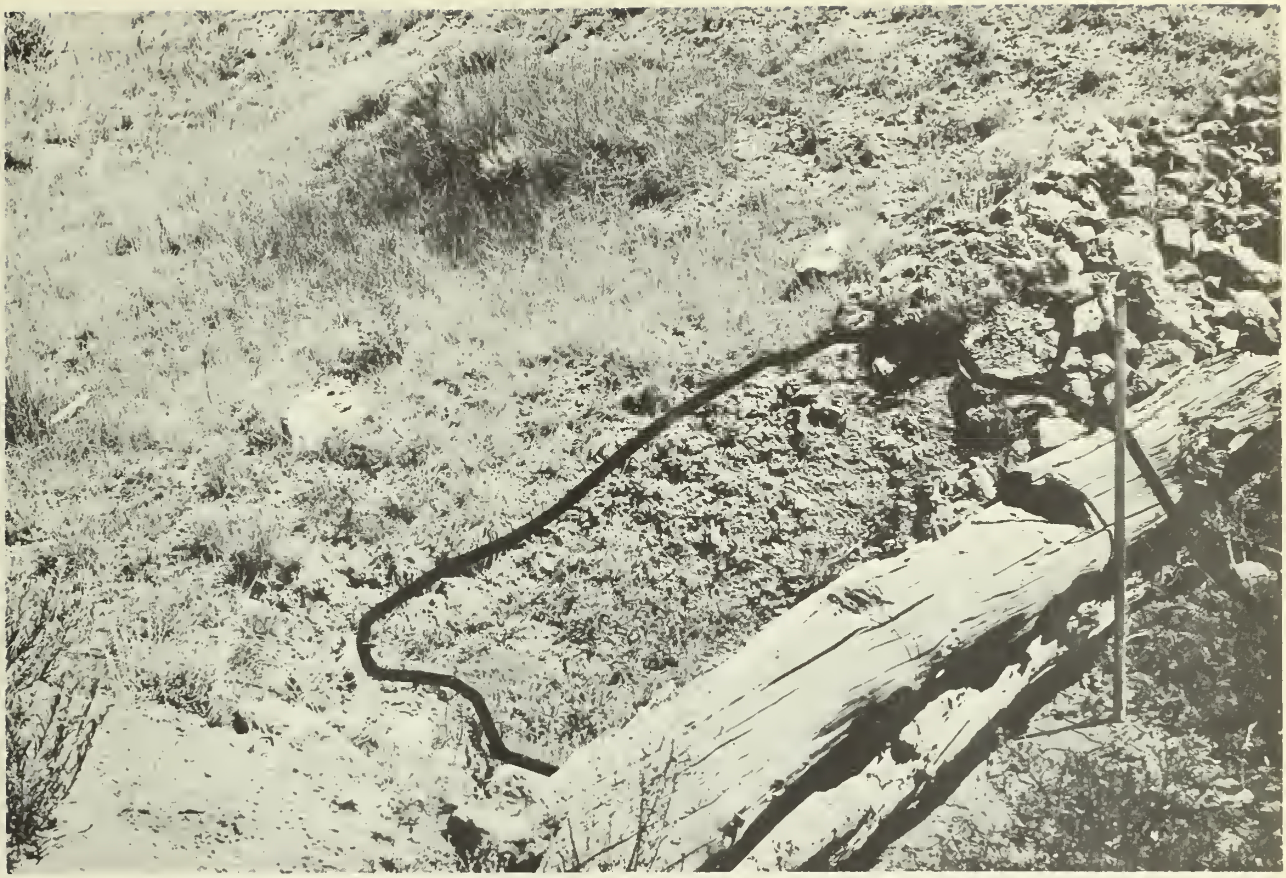

Figure 14.--At a distance of 210 feet below the last masonry structure a headcut in the channel bottom undermined check dam No. 37 to a depth of 1 foot. (Height of rod = 5.5 feet.)

Figure 15.--Beginning at the headcut shown in figure 14, channel depth increases rapidly downstream to 12 feet. Structure No. 45, located 490 feet downstream from the headcut, was undercut like all other dams in this segment. Cattle still graze the pasture to the left of the gully, but cattle grazing on the right bank was halted 22 years ago. The left bank is eroding faster than the right. (Height of rod = 5.5 feet.)

Figure 16. --Half a mile downstream from the headcut in figure 14, the gully becomes concave and gully depth decreases. Three V-shaped log dams were installed in this channel reach. Dam height equaled or exceeded channel depth, and the structures pointed downstream. Small spillways were provided in the center of the structures. All three dams lost their effectiveness when the two wings of the dam were pushed apart by the impact of a flash flow.

Figure 17.--Small Tributary gully is 377 feet long. The channel gradient averages 31.5 percent. The average channel cross section, computed from the cross sections at the structural sites, is 11.3 square feet; 2.3 feet is the average gully depth. Loose-rock check dams were installed in the 1930's. The average spacing between the dams is 21 feet. Fifteen of the 18 check dams restricted all the flow; none failed.

Figure 18.--In the 1930's Reuter gully was treated by the U. S. Civilian Conservation Corps. Loose-rock check dams were installed and willow root cuttings planted in the channel. Little evidence of the plantings can be detected now. The dams arch and possess wing walls that are placed upstream from the structures. Limbs from tree pruning were imbedded in the dams. The ends of the cuttings, projecting through the dam wall, point upwards to prevent the slipping of the upper rock layer. These cuttings caused the breakdown of the rim wall when the wood rotted. Consequently, otherwise successful structures lost part of their sediment deposits.

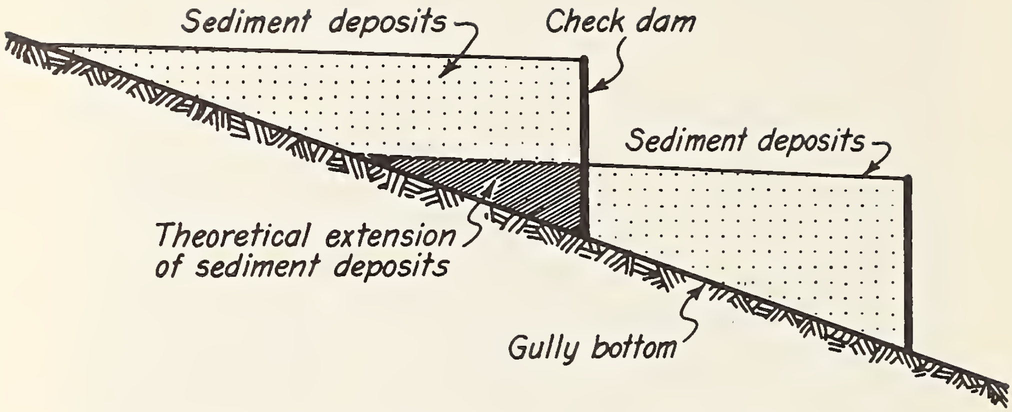

Figure 19.--The spacing of check dams was based on the head-to-toe rule. However, fewer dams would have been needed if they had been placed at the expected upstream toe of the deposits.

PRINCIPLES OF GULLY CONTROL

CLASSIFICATION OF GULLIES

The investigation of gullies in the Colorado Front Range indicates that two types of gully systems exist. This finding coincides with the gully classification of Leopold and Miller (1956) that was established in a study of gullies near Santa Fe, New Mexico. Figures 20 and 21 show the characteristics of a discontinuous gully system and a continuous gully as examples of the two types.

MECHANICS OF GULLYING

The mechanics of gullying can be explained by hydraulic regimen. Lack of appreciable runoff during the period of this investigation prevented quantitative analysis of hydraulic factors. Conclusions drawn from this investigation are reached inductively, supported by observations as found in the field and by previous research dealing with gully hydraulics (Leopold and Miller, 1956).

The upper segment of the Nursery gully system indicates that a discontinuous gully system may become a continuous one (fig. 20). Small headcuts in the upper reach of the lower segment show that this part had its origin in a series of individual gullies. No evidence could be found that showed the development of the lower channel reach. It is not known whether the characteristics of gully formation are different for a discontinuous and a continuous system. This knowledge would be of great importance to gully erosion control.

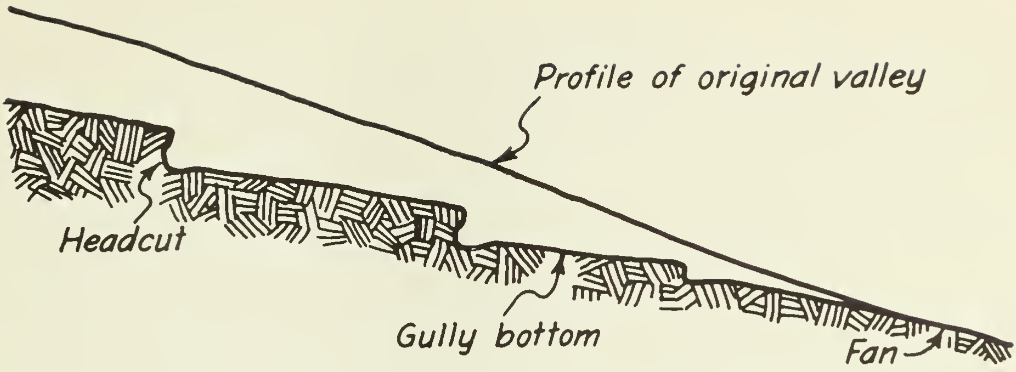

Figure 20.--This is a longitudinal profile of the upper segment of the Nursery gully system at the Manitou Experimental Forest. It consists of several individual discontinuous gullies. This system is characterized by (1) pronounced headcuts in the valley floor that mark the beginnings of individual gullies; (2) rapidly decreasing channel depth downstream; and (3) fans of sediment at the gully mouths. The slope of a discontinuous gully is always less than the original valley slope. Accelerated erosion advances and the distance between the gullies decreases until one continuous channel is established. In the drainage segment illustrated, the headcuts of the individual gullies are still visible in the channel, and channel depth is still decreasing rapidly. The fans below the individual gullies are obliterated by gully fusion, but a larger fan developed at the mouth of this system.

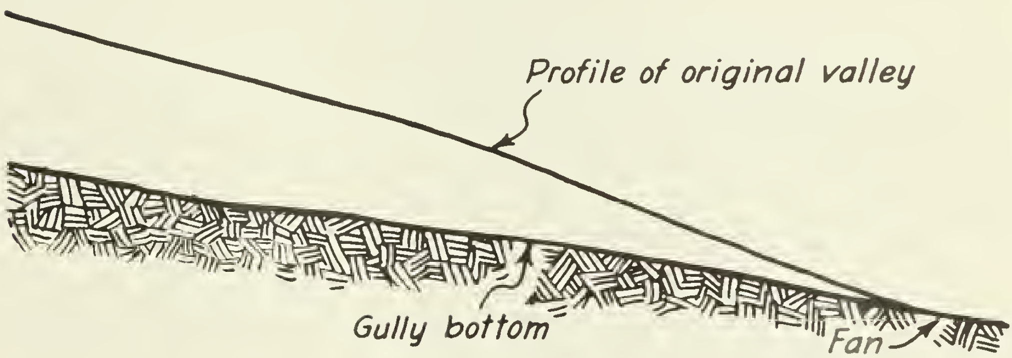

Figure 21.--This profile shows the lower segment of the Nursery gully system. It is a continuous gully. The channel slope approaches the gradient of the original valley floor. The gully starts in the upper drainage without a pronounced headcut. Rills and shoestring gullies mark its beginning. It deepens rapidly downstream to a point above the gully mouth. Here, the longitudinal profile becomes concave and channel depth diminishes until the gradients of the original valley floor and the channel bottom intersect at gully mouth. Below the gully mouth, a fan of sediment is formed on the main flood plain.

The longitudinal profile of any gully is the result of geologic and hydraulic factors. A discontinuous gully grows in both upstream and downstream directions allowing coalescence of individual gullies to take place. In a continuous gully the most pronounced channel changes occur in the lowest segment above the gully mouth where the difference between channel and valley floor gradient is greatest.

Velocity, width, depth, slope, and roughness parameter have a definite relationship to each other for a given flow. Expressed mathematically, the discharge in cubic feet per second equals the cross section of the flow in square feet times the velocity of flow in feet per second. This means that if one factor is changed, the others will change also. For example, an increase in roughness results in a slowdown of the velocity. Therefore, to accommodate a certain volume of flow, the gradient has to be increased or the channel increased in depth or width. Whether deepening or widening take place depends on (1) the geologic materials, and (2) the velocity of flow. Both govern the speed of bank and bottom cutting. Generally, both bank and bottom cutting occur at the same time, with one outranking the other in magnitude.

If the gradient is changed, a process similar to that in a discontinuous gully is introduced. A headcut will appear on the channel floor and proceed toward the headwaters. Thus, the new gradient is carried into the upper channel reaches.

In lower channel segments, headcutting and sediment deposition may counteract each other. If, for example, sedimentation proceeds upstream with greater speed than headcutting in the channel bottom, then an established headcut may be buried. This is of great importance in gully treatment.

At a gully mouth the channel fans out and the flow is distributed at a shallow depth over a large area. The fan cone with its typical semicircled circumference is created by sediment deposits on the main flood plain below the gully mouth.

CRITICAL LOCATIONS IN GULLY SYSTEMS

From the mechanics of gully development, it follows that there are certain active eroding (critical) locations in a channel. The characteristics of critical locations in a continuous gully system differ from those in a discontinuous system. Maximum erosion control and minimum costs can be obtained if the critical locations are treated first.

Since the discontinuous gully is moving in two directions--headcutting upstream and growth downstream by increase in the gradient--the two main critical locations are readily detected (see figs. 1 and 2). Also a headcut may develop within the channel of this system. This phenomenon most likely occurs in long channels with heavy sediment deposits at the gully mouth.

In a continuous gully the main critical location is the lowest channel segment near the gully mouth where the gradient has not yet reached equilibrium with the original valley slope. Here, pronounced changes of the channel base level take place.

The main critical locations in a gully system are critical (active) by the very nature of the mechanics of gullying. To achieve an effective gully control, other critical locations caused by meanders with sharp curves, dense brush, tree growth, or other constrictions in the channel should also be considered for treatment.

DESIGN OF CHECK DAMS

Hydraulic Requirements

The proper design of erosion-control structures is of great importance for successful gully treatment. Overdesign results in unjustifiable expenditures. Underdesign of one check dam can cause damage to all other installations upstream. This allows accelerated erosion to take place at a rate often greater than that in an untreated gully (see fig. 6).

The designer of check dams should consider the highest expected peak flow for the period of treatment. Difficulties in estimating this flow may arise because sufficient hydrologic data are not available. Often the designer has to rely on high water marks. But his judgment should be supported by experience and by data that were established under corresponding conditions.

The period of time required for the restoration of a watershed is unpredictable. The present investigation illustrates that 20 to 26 years are not sufficient to restore the vegetation on the watershed if the vegetal treatment consisted of cattle removal or controlled intensity of grazing only. Sheet erosion still occurs on the slopes and where control structures failed, gullying continues.

To be successful, a check dam must fulfill certain hydraulic requirements. The cross section of a channel is shaped by the hydraulic factors. Any dam changes the channel cross section and restricts the flow to some extent. The magnitude of the flow restriction is an important factor to structural success or failure.

Expected peak flow at the structural sites and discharge capacity of the check dams were calculated. From these calculations it was found that no structural failure occurred when the flow was less than 8 c.f.s. (see fig. 17). With this volume of runoff the related hydrostatic and dynamic forces are too small to cause destruction. (Calculations for all of the structures studied are presented in table 1, page 42.) This condition is represented by Small Tributary gully that lies in the headwater area of a larger drainage. The expected peak flow was estimated to be 1 c.f.s. at the gully mouth. No dam failed regardless of whether it accommodated the flow.

Most log check dams had small rectangular notches in the dam crest (see fig. 14). Since these notches accommodated only a fraction of the total flow, the bulk of the water spilled over the main crest of the dams. Therefore, the installation of notches is not worth while when they possess a discharge capacity smaller than the total flow.

Check dam No. 22, 15.5 feet long in Upper Trout Creek, represents such a structure with an insufficient notch. A peak flow of 46 c.f.s. was estimated. The size of the rectangular notch in the dam crest is 0.3 by 3.0 feet and its discharge capacity about 1.5 c.f.s. Hence, 44.5 c.f.s. must flow over the dam. Part of the waterfall would hit the unprotected banks because the channel bottom and apron below the dam are only 8.5 feet wide.

Requirements for the design of check dams to protect the channel below a structure are demonstrated and discussed in figures 22 through 25.

Figure 22.--Loose rock-mesh wire dam under construction by the U. S. Civilian Conservation Corps in 1939. A check dam should be keyed into the solid gully banks and into the channel bottom as shown. On the average, bank slots 2 feet deep and a core of 1-foot depth in the channel bottom were sufficient to anchor the structure. Bank keys should extend above the dam crest and into the channel to protect the gully banks from the erosive impact of the flood crest.

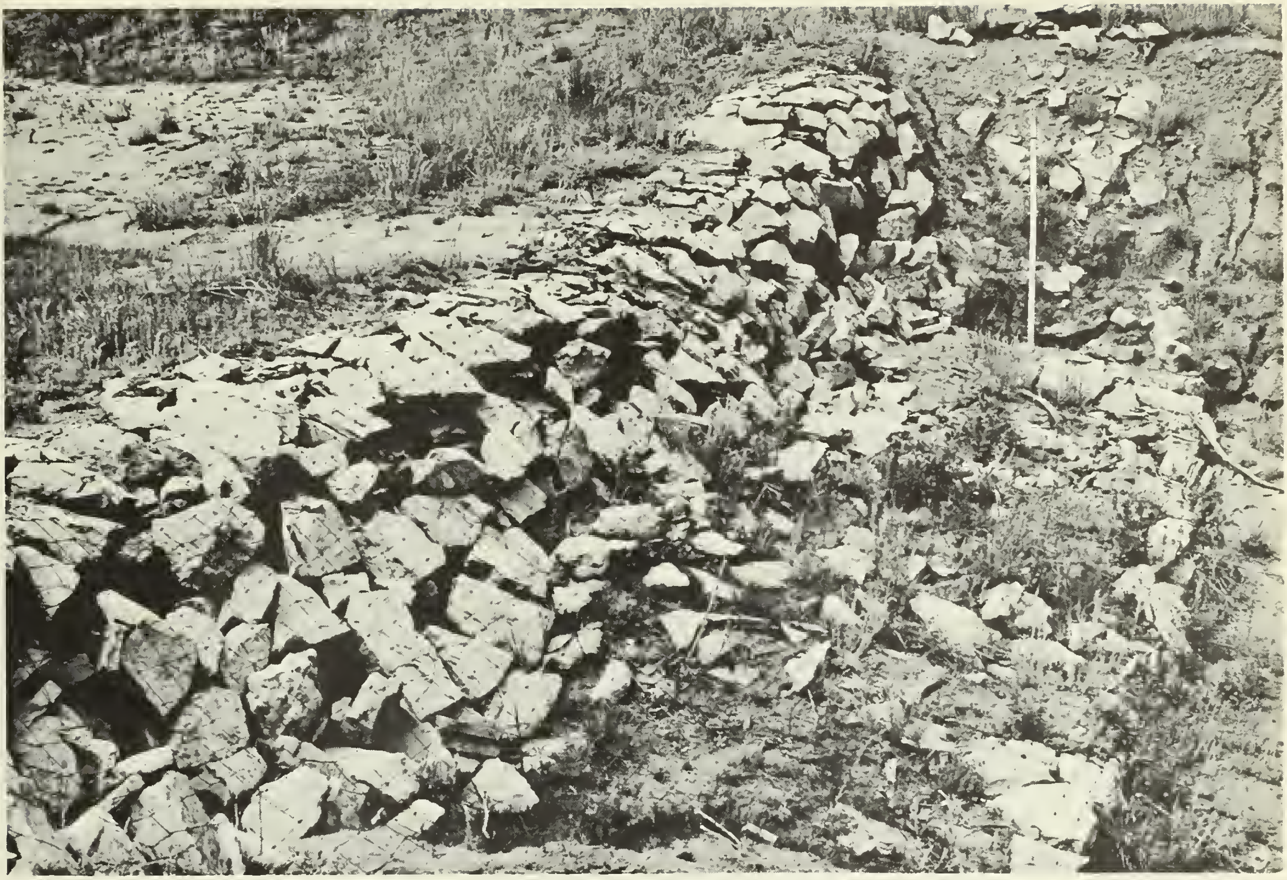

Figure 23.--This is the same check dam 20 years later (see fig. 22). It has a height of 6.5 feet and an apron length of 6.5 feet. The apron was effective. Since the falling water endangers the channel bottom below a dam, an apron is necessary to dissipate the energy of the water when it reaches the bottom. Insufficient quality and length of an apron may lead to undermining of the installation. Bank erosion below the check dam has started because bank protection was inadequate.

Figure 24.--Adequate bank shielding below a check dam is essential to prevent destruction of the dam keys. When the waterfall strikes the channel floor, eddies develop that wash against the banks. If not controlled, the eddies may wash out the banks and undermine the structural keys as seen above. The loss of the anchor will result in obliteration of the dam. When the effective length of a dam is greater than the width of the gully bottom, then part of the waterfall will strike directly on the bank. Bank shielding below such dams is particularly necessary. (Height of rod = 5.5 feet.)

Figure 25. --Successful bank protection below a check dam. The bank shield consists of layers of loose rocks held to the bank by galvanized wire mesh.

Most check dams represent rectangular or trapezoidal weirs. The designer of a dam should select weir dimensions that will accommodate the maximum expected flow. The cross section of the weir may be smaller in depth and greater in length or vice versa. The ratio between length of weir and resulting maximum head of flow will affect the height of the dam. In general, with increasing weir length and decreasing weir depth the height of the dam may be increased. Height determines the depth and the extent of the sediment accumulations upstream from the structure.

The depth of the sediment deposits at a check dam and their extension into the upper channel reach are important in the stabilization of a gully. These criteria are fundamental to the placement of check dams as discussed in the following section.

Placement

Check dams were spaced in the gullies by the head-to-toe rule. Thus, in channels with steep gradient many structures were needed. Often they were not more than 15 feet apart, with average height of 2 feet.

In general, sediment deposits accumulated by a dam possess a gradient greater than zero. If check dams are installed by the head-to-toe rule, then the upstream movement of the sediment deposits may be stopped by the upper structure. Thus, the application of this rule may lead to overdesign and the capacity of check dams is not fully utilized.

Overdesign in the spacing of dams is displayed by Reuter gully (see fig. 19). Since sediment deposits are 1 to 2 feet deep at the lower toe of the dams, the structures could have been placed farther apart. It appears doubtful that dams at the upper toe of all sediment deposits were needed. Certainly, fewer check dams would have stabilized the gully.

Where the magnitude of runoff and sediment production is small, as in the upper reaches of a watershed, the installation of numerous check dams is not justified. Small Tributary gully represents such a headwater area (see fig. 17).

Overdesign can be prevented by placing the structures where they are needed and where greatest benefit can be expected. These are the critical locations in a gully system. If additional check dams are needed, structural spacing should be determined by the expected length of the sediment deposits. Where there is not a sudden change in grade between the gradients of the deposits and the channel above it no check dam will be required to protect the upper gully bottom.

The gradient of the deposits above structures 2 to 3 feet high ranges between 5 and 6.5 percent in Reuter gully. The original channel gradient is 9.5 percent. Here, the gradient of the deposits is roughly half that of the channel gradient.

Construction Materials

The quality of the construction materials influences the design and the maintenance of control structures. Materials that require continued maintenance, such as unpreserved wood, should not be used. In gullies with ephemeral flow, the wood is submerged for short periods of time only. Therefore, it rots rapidly (see fig. 7).

Selection of construction materials should be based on the importance that a particular structure has in a gully system, on the magnitude of the expected flow, and on cost.

In general, the volume of the flow and its related hydrostatic and dynamic pressures are greatest at the gully mouth. Therefore, the most solid structure within the system is needed there. If this dam fails, then all structures in the gully may be destroyed by a new erosion cycle.

The lowest segment of the continuous Nursery gully illustrates reoccurrence of gully erosion caused by the failure of the dam at gully mouth. This dam was weaker than those installed upstream (see fig. 3). As a result of the structural failure, a new channel gradient was established that lowered the gully base level for 650 feet upstream. The headcut undermined four check dams and is still active (see fig. 21).

Most successful materials for check dams were steel, masonry, and loose rocks reinforced by galvanized woven wire. Gabion-type structures proved to be highly successful (fig. 26).

PROTECTION OF GULLY BANKS

The channel pattern of an ephemeral stream is not in a state of quasi-equilibrium as is common to waters running all year long. Often, the pattern of ephemeral streams is characterized by heavy meandering. Since most gullies possess unstable banks, meandering flow may widen the channel by bank cutting. If bank cutting occurs, then valuable surface soil is lost.

Usually, critical channel curves have a small radius and a steep bank (see fig. 2); hence, they are easy to detect. Bank cutting takes place both at high and low flows. Even shallow flows, when directed at a bank, will scour and undermine (fig. 27). If a bank is undermined, then it tumbles into the channel and provides a sediment source for later flows. Mechanical devices are necessary to protect such eroding banks.

Often, a critical location is created by a tributary at the site where it joins with the main gully. Here, the flow of the tributary may force the stream toward the opposite bank, cause cutting, and create almost vertical bank slopes.

These banks should be protected by revetments to deflect the stream to a direction parallel to the centerline of the channel. If this cannot be done, armoring of the exposed bank is necessary.

Figure 9 illustrates revetments that are placed at the point of confluence of the Nursery gully and a tributary. These crib jetties direct the flow toward the opposite bank where scouring took place. Revetments, installed parallel to the bank, would have been more effective.

In ephemeral gullies, banks may also be steep in straight reaches. A dense plant cover protects the rim of the channel more efficiently than a depleted cover (see fig. 15).

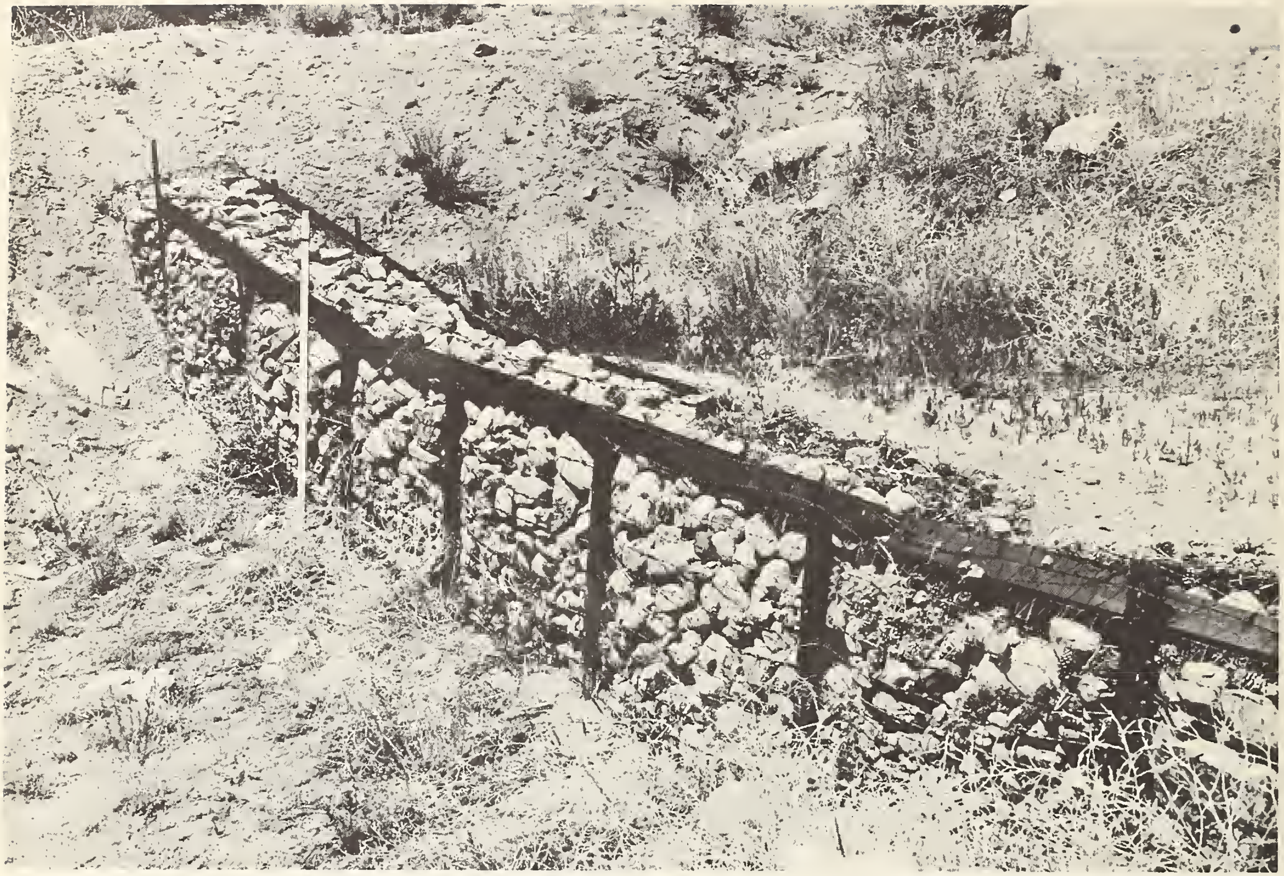

Figure 26.--A highly successful gabion-type check dam built from steel rods, galvanized woven wire, and cobblestones. Structure installed by Colorado State Highway Department in connection with the relocation of U. S. Highway 24 in 1938. (Height of survey rod = 5.5 feet.)

Figure 27.--
Flows with shallow depth undermine gully banks. Nursery gully, Manitou Experimental Forest. (Height of rod = 5.5 feet.)

In most ephemeral gullies, mechanical shielding of extensive bank segments is not feasible. Here, other measures such as short-grass lining should be applied. Ree and Palmer (1949) demonstrated by experiments that short grasses controlled bank and channel-bottom erosion very effectively.

Since vegetation cannot be established on vertical slopes, banks with steep slopes should be brought to an angle of repose where channel depth is not excessive. This measure was performed successfully in upper Trout Creek gully where the gully was continuous and banks were less than 5 feet high (see fig. 12).

The grading of banks may be deferred until the channel bottom is raised by sediment deposits that accumulate above check dams. Then, steep banks can be sloughed to an angle of repose without enormous losses of surface soil.

PLANTINGS

Willow and locust were planted at check dams and throughout the gully in the channel bottom. Survival of the locust was poor, and they did not migrate. Willow plantings had excellent survival. However, willows can cause difficulties in gully stabilization. Plants and branches float downstream, take root, and start dense, new stands where obstruction to waterflow is undesirable (see fig. 10). Choking of channels with willows may cause undercutting of banks and widening of gully bottoms.

As a general principle, woody vegetation should not be established within the high water channel where obstruction of flow would cause the stream to go out of banks or undercut gully walls. When trees and shrubs are planted around wings of check dams and at the top of gully banks, care should be used. Species that will not spread to the moist sites along the channel or to sediment accumulation areas should be selected.

TREATMENT OF GULLY SYSTEMS

Four gully systems were investigated. The Nursery gully system consists of two parts that differ distinctly. The upper segment is a discontinuous system; the lower segment is a continuous system. Continuous gully systems were also studied at the Trout Creek watershed.

The mechanics of gullying in a discontinuous and a continuous gully system are different. A discontinuous gully tends to expand upstream and downstream. Its critical locations are at gully headcut and at gully mouth. Main structures should be placed at these locations.

In a continuous gully, the main active (critical) location is the lowest segment near the gully mouth. There, changes in channel gradient take place and, if not controlled, may lead to further channel deepening of the whole system. Consequently, a main structure is needed at the gully mouth.

Critical conditions in other channel segments may be produced by restricting flow. Flow restrictions occur if the channel cross section is reduced to dimensions that do not accommodate a stream of a given velocity. Then, as accelerated erosion takes place gullies widen, deepen, or both. Trees and shrubs should not be established in a gully if flow is likely to be restricted.

To be successful, the design of a check dam should also comply with the hydraulic requirements of the channel. Following principles were established:

1. A check dam should accommodate the highest expected peak flow for the period of treatment.

2. A check dam should be keyed in the channel bottom and into the channel banks.

3. Sufficient structural bank protection and adequate channel floor protection below a dam is needed.

4. Adequate construction materials should be used.

The extension of the sediment deposits above a check dam depends on the gradient of the channel, the velocity of the flow, the specific weight, the shape and size of sediment particles, and on the height of the dam. Under given channel and flow conditions, the sediment accumulations will extend farther upstream from a higher installation than from a lower one. When the new channel gradient is established, a critical location may occur at its upper end and the new slope may be carried into the headwaters by headcutting of the channel floor. This action is most likely to take place if a pronounced break in grade exists between the slope of the sediment deposits and the connecting channel segment above.

This new critical location should be determined before the new base level is established. Plant and soil conditions vary greatly in a watershed and conditions in ephemeral gullies change from storm to storm and even during the course of a flow. Extension of sediment deposits above a dam cannot yet be calculated because of insufficient knowledge of the interacting variables. Meanwhile, empirical data from similar field conditions should be used.

The mechanical treatment of a gully should continue over a period of time. The first step is to install check dams at critical locations and treat critical banks. After treatment, periodic inspections are imperative to determine the need for further installations or repairs.

When check dams have effectively filled with sediment, the stream velocity will be more rapid than it was during the filling period because the pools behind the check dams act as stilling basins. However, the velocity will not be so great as it was without structures, and erosive forces will be less. An equilibrium is eventually achieved between the stream velocity and the larger particles that finally form the stabilized bed.

RECOMMENDATIONS

The final objective of all gully control is to stabilize the channel by vegetation. Often the condition of gullies is such that this objective cannot be achieved directly. Gullies develop steep banks and a vegetative cover cannot become established. Incisions in the valley floor are so deep that the ground water table on the surrounding land is lowered and plant growth is impeded. To create conditions more favorable to the restoration of vegetation, mechanical treatment is needed. The specific purposes of this treatment are:

1. To control the channel gradient until channel stabilization by vegetation occurs.

2. To raise the channel base level;

3. To stabilize channel banks.

To help guide future gully control, the following principles and recommendations are summarized:

1. Determine the type of system, continuous or discontinuous.

2. Determine the critical locations in the gully system.

3. Estimate the highest expected storm runoff for the period of structural treatment.

4. Estimate the highest expected peak flow at all structural sites.

5. Design structures to accommodate this flow.

6. In discontinuous gully systems, control headcuts and lower channel segments near the gully mouth by structures. Install water spreaders below the system if the lowest gully mouth is not on the main flood plain.

7. In continuous gully systems, start structural treatment at the gully mouth. Place strongest check dam there.

8. Install structures below headcuts located in the channel bottom.

9. Treat critical locations such as sharp curves in meandering gullies or cutting banks by revetments. Install these devices parallel to the bank.

10. Do not deflect flow toward channel banks.

11. As a general principle, do not plant woody vegetation within the high-water channel where obstruction of flow would cause the stream to go out of banks or undercut gully walls.

12. Remove boulders, trees, bushes, and other flow restrictions that would result in bank cutting or overtopping of the channel.

13. To reduce the amount of earth movement and surface soil disturbance required, defer bank sloping until channel bottom is raised.

14. After treatment, inspect gully periodically to determine needs for maintenance and further control measures.

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APPENDIX

EXAMPLES OF GULLY CONTROL

Three gully systems are selected to demonstrate gully control as proposed by this study. One of the systems represents a discontinuous type and two are continuous gullies. The latter had been treated by check dams and willow plantings 20 to 26 years ago. These measures were successful only in part because:

1. The critical locations in the system were not recognized;

2. The hydraulic requirements for check dams were disregarded;

3. Inadequate construction materials were used;

4. The adverse effects of willow plantings in the channel were neglected; and

5. No maintenance was applied.

Retreatment is needed to stop reactivated erosion and to preserve the benefits derived from the first treatment.

The discontinuous gully system was not treated. Treatment is necessary now to prevent the individual gullies from further expansion and coalescence (fig. 28).

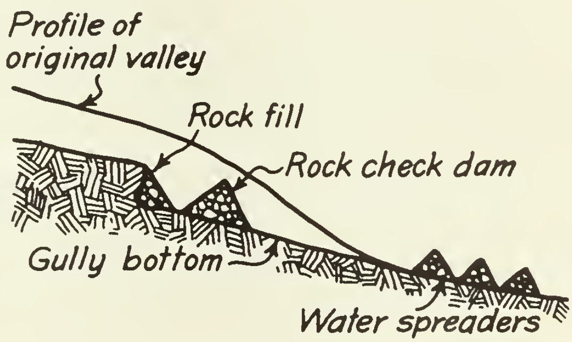

Figure 28.-- Proposed treatment of partially fused discontinuous gullies.

Nursery Gully System

Discontinuous Segment

Field inspections of this gully system indicated that the gullies are still deepening and expanding longitudinally. In the segment shown by figure 20, the individual gullies are already coalescing.

Whether or not the gullies join, the headcuts should be treated to lead the water away from the vertical cut so that the waterfall cannot undermine the head. When the water reaches the channel bottom, the accelerated velocity of flow, induced by the change of gradient, should be dissipated. Otherwise, scouring will take place.

The segment demonstrated by figure 20 has a maximum channel depth of 4 feet. It is proposed to use loose rock as the construction material. The headcuts will be filled with loose rocks and sloped $1\frac{1}{2}:1$ into the channel. At the toe of the fill a check dam is needed to stabilize the fill and to dissipate the energy of the flow. The check dam should possess a discharge capacity at least equal to the estimated peak flow from the design storm.

During succeeding flows, sediment will accumulate above the dam. These deposits will slope gently toward the edge of the headcut and protect the fill.

Where individual gullies do not fuse, a check dam should be placed near the mouth of each gully. The purpose of this dam is to raise the channel gradient to prevent the gully from getting longer.

When individual gullies are in the process of coalescence (see figs. 20 and 28), check dams are not needed at the lower ends of gullies, for the headcut treatment will control the gradient of the upper channel reach.

Below the discontinuous gully system, water spreaders should be installed to prevent the development of a new gully. Spreaders need not be applied between the individual gullies within the system because the water flowing in the channel will facilitate sediment deposition and vegetative growth.

With the application of these measures, the first phase of gully treatment is finished. The necessity for additional controls will be determined by future erosion.

Continuous Segment

The retreatment of this gully starts with the removal of all flow restrictions such as dams that do not possess sufficient discharge capacity or that have failed for other reasons, and stands of trees and bushes that choke the channel and cause undercutting of banks and widening of gully bottoms.

A check dam should be installed at the main critical location near the gully mouth. Here, the sturdiest structure in the system is placed. Check dams to hold large sediment deposits that are still in place should also be built. For example, at structure No. 10 (see fig. 21) a new check dam is needed to prevent further headcutting through old sediment deposits.

Critical locations on banks should be protected by revetments installed parallel to the banks. Steep banks should be graded to an angle of repose. This work finishes the first phase of the structural gully treatment.

Upper Trout Creek Gully

The upper segment of the gully is well stabilized by vegetation (see fig. 12) and the deterioration of the log dams does not cause an erosion hazard. Inspection showed that control of the total system may be lost if treatment is not applied to the main critical location that lies 1.25 miles below this stable segment. Here, check dams failed because of inadequate design and construction (see fig. 16).

When the structures failed, a new channel gradient was carried upstream by headcutting. This headcut is now 0.5 mile upstream from the structures that failed and 100 feet above the national-forest boundary. While moving upstream, the headcut undermined and destroyed 15 check dams (see fig. 15).

Five masonry spillways, installed above the present headcut, possess an efficient water- and sediment-retarding capacity. Yet, while these structures slowed down the rate of headcutting, they will not be able to prevent the new gradient from proceeding into the headwaters. If the main critical location and the headcut are not treated, then these solid structures will eventually become victims of the new gradient. Consequently, a check dam should be installed at the main critical location and at the headcut.

Future periodic inspections are needed to determine if and where structures should be placed between the treated critical locations. Their purpose will be to raise the channel base level and hence help stabilize the gully.

G U L L Y   S U R V E Y

Kind of structure: Number:

Age of structure: Date:

Success (S) or Failure (F): Location:

Description of structure and channel:

Channel cross section

Structure cross section

Weir breadth:

Channel length (structure to structure):

Gradient [Old (determined for channel segment):
[New (present day; between structures):

Sediment trapped

Soil: Parent material:

Photograph:

Figure 29. --Sample of field-data form used for surveying and evaluating gully-control structures.

Table 1.--Expected peak flows and maximum discharge capacities of check dams in continuous gullies

Structure No.	Success (S) or Failure (F)	Expected peak flow at location of dam	Discharge capacity of dam
		c.f.s.	c.f.s.
MANITOU EXPERIMENTAL FOREST NURSERY GULLY (Check dams built from logs and loose rocks)			
1	F	60	15
2	S	61	272
3	S	62	143
4	S	65	345
5	F	66	36
6	F	82	8
7	S 1/	--	--
8	S	90	868
9	S	91	348
10	S	92	372
11	F 2/	93	113
12	F 3/	93	320
13	F	94	34
SAN ISABEL NATIONAL FOREST UPPER TROUT CREEK GULLY (Check dams built from logs and loose rocks)			
UPPER SEGMENT			
1	S	41	432
2	S	41	321
3	S	41	252
4	S	42	255
5	S	42	264
6	(4/)	42	50
7	S	43	152
8	S	43	159
9	S	43	219
10	S	43	438
11	S	43	293
12	S	43	504
13	S	44	457
14	S	44	372
15	S	44	380
16	S	45	500
17	S	45	654
18	S	46	459
19	F 5/	46	373
20	S	46	169
21	S	46	75
22	S	46	237
23	S	46	341
24	S	47	347
25	S	47	277
26	S	47	167
27	F	47	45
28	F	47	9
LOWER SEGMENT			
32	S	260	1,066
34	S	267	1,056
35	S	271	1,106
LOWER SEGMENT (continued)			
36	S	274	641
37	F 6/	278	397
38	F	281	123
39	F	284	545
40	F	287	409
41	F	290	589
42	F	293	1,095
43	F	296	850
44	F	299	1,204
45	F	302	693
SMALL TRIBUTARY GULLY (Check dams built from loose rocks)			
1	S	1	2
2	S	1	0
3	S	1	0
4	S	1	0
5	S	1	0
6	S	1	0
7	S	1	13
8	S	1	5
9	S	1	0
10	S	1	0
11	S	1	0
12	S	1	0
13	S	1	0
14	S	1	0
15	S	1	0
16	S	1	0
17	S	1	0
18	S	1	0
REUTER GULLY SEGMENT IN CENTER OF GULLY SYSTEM (Check dams built from loose rocks and cuttings from tree pruning)			
9	F	9	0
10	S	9	12
11	F 7/	10	0
12	S	10	11
13	S	10	52
14	F	11	0
15	F	11	0
16	S	11	41
17	S	11	33
18	S	12	37
19	S	12	65
20	S	12	34
21	S 8/	--	--
22	S	13	67
23	F	13	8

1/ Not representative; original dimensions in question.
2/ Secondary failure; caused by obliteration of dams No. 12 and 13.
3/ Secondary failure; caused by obliteration of dam No. 13.
4/ Borderline case.
5/ Construction inadequate.
6/ Dams No. 37-45 are secondary failures caused by structural obliteration approximately 2,000 feet below dam No. 45.
7/ Sediment accumulation apparently occurred under small flows but large flows broke the dam.
8/ Not representative; original dimensions cannot be determined.